M.O. 514 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 78. No. 921. MARCH 1949

FORECASTING RESEARCH

By R. C. SUTCLIFFE, Ph.D.

Any research, if it is a contribution to meteorological knowledge, can hardly fail to have value, immediate or potential, in weather forecasting. This is not a controversial statement for the forecaster is concerned with the evolution of meteorological conditions, with the changes taking place in the physical properties of the atmosphere, and research which throws no light on these things is hardly meteorology, however admirable it may otherwise be. Nevertheless, those who judge forecasting without first-hand experience may tend to regard it as concerned with a limited field of science, and to infer that research of value in forecasting must be highly specialised. This would misrepresent the case seriously and the true position may perhaps be illustrated by remarking upon the relevance to forecasting of a few lines of research selected from diverse fields less obviously apposite to the work of the forecaster.

A particularly good example is the study of climatic change through the ice ages—particularly good in that a very eminent meteorologist recently commended the subject to his colleagues as being not only fascinating but also, to the best of his belief, quite useless. He was on very unsafe ground. If we were to know with certainty the causes of climatic change in geological time we might hope to judge whether the same causes could explain the striking amelioration of winter climate in north-west Europe during the past century and to judge whether the trend would persist in the next decade, with no negligible significance for the economic recovery in these lands.

We need choose no special illustration from climatology; for this, even if we exclude synoptic climatology, is the background of past records which the forecaster ignores at his peril. Empirical forecasting, whether based on formulated rules or on experienced judgment, can be claimed as pure climatology—an integration of past events—and I would urge forecasters and climatologists to get closer together, the better to co-ordinate their research requirements.

It is rather in the field of physical experiment and theoretical research that we may expect to find something which by no stretch can be called forecasting research, but it is not easy. When M. Dessens succeeds so elegantly in capturing natural atmospheric nuclei on spiders' webs of fineness 1μ he may not be hoping to improve the weather forecast but he is nevertheless engaging on an essential and very promising line which in due course may decide whether

the forecaster must study nuclei conditions to predict some of the vagaries of fog, cloud and precipitation. Again, when Dr. Robinson, at Kew Observatory, studies radiation problems and gives us a modification of Elsasser's radiation chart he is well employed in the scheme of forecasting research; we need such results very badly indeed, for in both short-range and long-range problems we must judge in some way how the temperature of the free atmosphere will change. We might not hope to calculate the answer regularly from theoretical formulæ, this may prove for some time to be impracticable, but if we wish to develop even approximate methods we shall only be surely guided when the fundamental theory is well understood.

To take one last example, much highly theoretical and special experimental work is being carried out in connexion with evaporation and soil moisture with the application to agriculture immediately in mind; but the forecaster, apart from his direct agricultural interests, watches the progress with much interest and is already relating the results with his fog problem and with the more general question of the changes of moisture content in the free atmosphere.

If all meteorological research facilities in the country were controlled by the weather forecasters, and even if these people had a strictly utilitarian attitude, there might be some change of emphasis, of priorities, but I doubt whether the over-all picture would be very much altered. Even engineers recognise the need for fundamental research for practical ends; there is only one set of problems ultimately and the forecaster is concerned with them all.

And not only do I argue that all meteorological research is forecasting research but would affirm that experience in forecasting is the best introduction to almost any branch of meteorological research, whether climatological, experimental and observational, or theoretical. It may seem that to spend a year or a few years in predicting weather is a dubious investment for the research scientist; but this is not an informed point of view. The " forecaster ", wherever he is employed, probably spends quite a small proportion of his time in predicting. Most of his efforts must go into studying present and past conditions, in co-ordinating the observations, analysing the situation and watching the course of change in the physical state of the atmosphere. The need to forecast is, perhaps, to the research mind, an irksome discipline but an entirely profitable one supplying just the necessary corrective to the wandering mind, to the eager theorist who would escape reality. Experience in a forecasting service, like little else, drives home the facts, such as they are known, about the atmosphere and allows the forecaster to formulate research problems about the real atmosphere—we may perhaps here agree that natural science should describe nature. If any young scientist is thinking of meteorological research as a career, whether he is a climatologist, a mathematician or an experimental physicist, I would quite cheerfully recommend him to spend a year or two letting his ideas take shape while he learns something about the atmosphere in the business of forecasting.

The above broad comments on the relationship between forecasting and research are, I think, a necessary preliminary if forecasting research proper is to be seen in true perspective and not as something rather outside the main stream of the science: its demands upon and its inspiration to research are all-embracing, its field co-extensive with the science of meteorology.

As, however, we do use the term "forecasting research" some limitation of scope must be implied; we are thinking of research which is specifically undertaken with the object of improving the standard or extending the scope of forecasting and to appreciate the requirements it is necessary to understand how the forecaster works—for forecasting is more than science, it is a professional occupation.

Weather forecasting, as traditionally carried out, follows a procedure which is in principle remarkably direct and simple to understand. The many observations of pressure, temperature and humidity, wind and weather phenomena, obtained from a wide area and made more or less synchronously, are plotted on geographical maps of the area and made surveyable by various cartographical methods. The result is, in effect, just a small-scale model of the atmosphere itself, represented, it is true, not as a solid model but by various sections and soundings, quasi-vertical and quasi-horizontal, yet providing to the forecaster a three-dimensional model of the atmosphere which he visualises as an entity. The process, which is conventionally referred to as the analysis of the situation, is actually a process of synthesis: from the many discrete observations the field distributions of the various properties and phenomena are inferred. From a sequence of observational material the synthesis is extended to the fourth dimension; the forecaster has in his mind the changing distribution patterns of pressure, temperature, wind and so on, synthesised from the observations, and forecasting is the extrapolation of the model into the future.

The technique of representation is fundamentally geographical or geometrical, primarily cartographical. It will be at once clear that success in forecasting by such model-making will depend on many factors and that the demands upon research will be diverse. The first requirement is adequate observations of adequate quality; the second, the development of cartographical techniques to represent the essential factors and features of the continuous fluid as completely and as clearly as possible; the third, technical skill in using the methods and in visualising the essentials of the actual atmosphere from the model provided—and this is where natural aptitude counts for much; the fourth, scientific skill in determining the most likely structure where observations are inadequate; and last, scientific skill in making the extrapolation into the future. I exclude, in connexion with research, the essential personal qualities, organising ability and general judgment, which are required for success in any profession: with so much to do the forecaster must above all keep his head.

It is therefore impossible to divorce forecasting research from the development of techniques, and it is obvious that skill in the actual prediction is interwoven with skill in the analysis and synthesis of observations. In the earliest days, as would be expected, there was an immediate jump forward to a considerable success based purely on experience and quite empirical extrapolation of the observed trends in the model. It would be impossible for any intelligent person, with the barest scientific knowledge, to miss the many obvious regularities, the more or less steady displacements and developments of circulation systems and rain areas, seasonal and topographical effects, diurnal variations and the like. These empirical methods elaborated and improved over the years remain a valuable part of forecasting, and, many will say, the greater part. It would however be quite untrue to regard established methods of forecasting as purely empirical, indeed there are few principles introduced which are not based

on physical insight or which have not been supported by physical argument and, in so far as exact formulæ are not established, the position should be not a discouragement but rather a challenge to the research scientist.

In a further article I hope to discuss in more detail the types of problems which arise and some of the more immediate lines of research and I may perhaps satisfactorily conclude this brief introductory survey with some very general comments on the probable trend of practical forecasting research in the next ten or twenty years. One avenue I may call the purely empirical: the use of organised statistical methods, correlation coefficients, regressions, periodicities and so on, which provide numerical values of physical quantities with statistically determined probable errors. This field has been worked over industriously; it has so far yielded very little, certainly nothing commensurate with the effort expended; it is still indeed far from being exhausted but, in spite of some new enthusiasm in certain quarters, I expect it to make no great impact on forecasting practice. I believe we know too much about the physical problems already to regard blind statistical research as a promising tool, although as a measure of the validity of methods inspired by physics the statistical analysis has its definite place.

At the other extreme is pure theory leading eventually, one may hope, to the calculation of the future state of the atmosphere with an accuracy restricted only by the uncertainties of "initial and boundary conditions". With or without the aid of electronic machines these methods are I believe still a long way off and I am not sure that much of the thought being put into the problem is not premature. The difficulty is that the fundamental differential equations are not yet adequately formulated. The magnitudes of the physical effects of radiation, turbulence and convection on the temperature of the free atmosphere, to take but one important factor, are not known with sufficient accuracy to allow calculation to be carried through successfully even in a simplified case. Further, topographical effects clearly dominate the circulation and to express Greenland in differential equations is not easy. Pure theory carried through on simplifying assumptions will certainly contribute much more to our understanding of the physical processes and will direct the attention of the forecaster to the quantities which he must observe, estimate or calculate if he is to make progress but there is a long way to go before he can throw away his synthetic model-making and reduce his problem to computations.

The most fertile line for early practical results, lies, I think, along the extension of established channels, somewhere between pure empiricism and pure theory, what we may call rational empiricism. Theory will tell us what are the essential factors and how they are related but not with adequate precision to provide the best working tools. By co-ordinating experience, not omitting systematic statistical studies, empiricism will continue to fill the gap which theory leaves. In this development the research forecaster, and in his turn the routine forecaster, must, however, be prepared to consider carefully much more than the direct observables and the simple gradients on which he has based most of his methods in the past. There is already sufficient theory to establish the prognostic significance of derived indices, parameters and functions such as vorticity and divergence, geometrical properties of the temperature distribution, stability criteria, circulation indices and so on. Perhaps progress in the early future will come primarily from the systematic introduction of such factors into routine techniques.

The present position is truly exciting. At last we are being provided with data which give us something approaching a factual picture of the behaviour of the atmosphere in three dimensions. The field is open to a comprehensive attack from all sides and the physicists and mathematicians should be on their mettle to extend their claim and to squeeze the empiricist and statistician out of this territory of natural science. Meanwhile forecasting research must look both ways and turn every success to its own advantage.

THE ACCURACY OF A MEAN OF *n* TEMPERATURE OBSERVATIONS AS AN ESTIMATE OF THE MEAN TEMPERATURE FOR A PARTICULAR MONTH

By N. CARRUTHERS, B.Sc.

Let us consider a month of 31 days and, in the first instance, suppose that the value aimed at is the 31-day temperature mean formed by taking one observation at a fixed hour on each day throughout the month. The goodness of representation of this mean by only n observations (assuming each observation to be on a separate day and at the same fixed hour) depends not only upon the number n but also on how the observations are scattered through the month. On account of persistence, ten observations at three-day intervals will generally give a better estimate of the 31-day mean than will 14 or 15 observations on consecutive days.

The " persistence length " for temperature has been found to be about three days. For scattered days, means of ten or fewer observations will be distributed about the 31-day mean with a standard deviation (σ' say) of $\sigma/\sqrt{n}$, where σ is the standard deviation of single observations about the mean; but, for $n > 10$, the relation between σ' and σ is not quite so simple. The closer n is to 31 the nearer is the n-day mean to the 31-day mean and so the smaller is σ'; but, at the same time, more of the n values are on consecutive days so that persistence comes into play tending to increase the standard deviation σ'.

A convenient relation for $n \geqslant N/3$ is given by $\sigma' = \sigma\sqrt{[3(N-n)/(2Nn)]}$ where N is the number of days in the month. This expression is of the correct dimensions in n (*i.e.* $n^{-\frac{1}{2}}$) and decreases from $\sigma' = \sigma/\sqrt{n}$, when $n = N/3$, to zero when $n = N$.

Where the observations are consecutive, the standard deviation of the n-day means will be $\sigma' = \sigma\sqrt{(3/n)}$ when n is ten or less, because n consecutive observations are equivalent to only $n/3$ independent observations. When n is greater than ten, σ' will lie between $\sigma\sqrt{(3/n)}$ and $\sigma\sqrt{[3(N-n)/2Nn]}$, approaching more nearly the latter expression as n increases.

The n-day means are distributed normally about the 31-day mean. This is true, or nearly so, at all levels in the upper air even although, near the mean height of the tropopause, the distribution of the individual values is not " normal ". If therefore d is the amount by which any n-day mean departs from the 31-day mean, we are able to estimate the proportion of occasions on which a given value of $|d|$ is equalled or exceeded by means of tables of the " probability integral ". Table I gives related values of λ and P where $\lambda\sigma'$ is the deviation equalled or exceeded on P per cent. of occasions, σ' being given (as above) by the relations (for scattered observations):—

$$\sigma' = \sigma/\sqrt{n}, \qquad n \leqslant \mathcal{N}/3 \qquad .. \quad (1)$$

$$\sigma' = \sigma\sqrt{\left\{\frac{3(\mathcal{N}-n)}{2\mathcal{N}n}\right\}}, \quad n \geqslant \mathcal{N}/3 \qquad .. \quad (2)$$

The expressions (1) and (2), with the aid of Table I, enable us when σ is known to compute the minimum number of (scattered) observations required to give an estimate of the mean for the month to any specified degree of accuracy. Suppose that σ is measured in degrees Fahrenheit and an accuracy of u°F. is required on at least $(100-P)$ per cent. of occasions. To obtain this degree of accuracy we require $\lambda\sigma' \leqslant u/2$, the value of λ being that corresponding to the chosen value of P in Table I. Using this relation, we find from (1) and (2) after transposing,

$$n \geqslant 4\lambda^2\sigma^2/u^2 \qquad \text{where } \lambda\sigma/u \leqslant \sqrt{(\mathcal{N}/12)} \qquad .. \quad (3)$$

$$n \geqslant 1\bigg/\left\{\frac{1}{\mathcal{N}} + \frac{u^2}{6\lambda^2\sigma^2}\right\} \qquad \text{where } \lambda\sigma/u \geqslant \sqrt{(\mathcal{N}/12)} \qquad .. \quad (4)$$

TABLE I—RELATION BETWEEN λ AND P

If the mean of n observations within an $\mathcal{N}$-day month differs by d from the mean of the whole $\mathcal{N}$ observations (one each day), and σ' is the standard deviation of n-day means about the $\mathcal{N}$-day mean, then $|d| \geqslant \lambda\sigma'$ on P per cent. of occasions.

P (per cent.)	1	5	10	20	25	33·⅓	50
λ	2·576	1·960	1·645	1·282	1·150	0·976	0·675

P (per cent.)	4·6	13·4	31·7
λ	2·00	1·50	1·00

Table II gives average values of standard deviation of temperature at different levels over Larkhill. These were determined by taking the square root of the average of the variances for the four seasons of the year, each variance being that of all observations during the years 1942–44 about the seasonal mean for the whole period. The average value of the standard deviation within a specified month (referred to in this note as σ) is less than the standard deviation for the same level in Table II, probably by about 5 to 10 per cent.

TABLE II—STANDARD DEVIATION OF UPPER AIR TEMPERATURE
(Average seasonal values over Larkhill, 1942–44)

Pressure level (mb.)	900	700	500	300	250	200	170	150	130	100	80
Standard deviation (°F.)	7·25	8·04	8·40	6·72	7·11	10·94	11·20	10·38	9·11	9·09	9·88

These values are a measure of the variability of temperature observations (during one season of the year) about the long-period mean.

Table III gives, for the range of values of σ likely to occur in the upper air over England, the number of observations n required for a mean, correct to within 5, 2 and 1°F. on 75 per cent. of occasions and to within 5°F. on 66⅔, 75 and 95 per cent. of occasions. These values of n have been computed from the expressions (3) and (4) with the aid of Table I. They are given to a decimal place to facilitate rough interpolation.

Table IV relates n with u and $(100-P)$ in a different way, showing how often an accuracy u°F. is obtained with specified values of n when $\sigma = 7$°F. and when $\sigma = 10$°F. In general 6 or 7 observations will give on half the occasions an accuracy of 5°F. but about 20 observations are required for an accuracy of 2°F., and about 27 for an accuracy of 1°F. on half the occasions.

TABLE III—MINIMUM NUMBER n OF TEMPERATURE OBSERVATIONS WITHIN A 31-DAY MONTH FOR AN ESTIMATE OF THE 31-DAY MEAN

Standard deviation (σ)	Number of observations				
	Correct to 5°F.			Correct to 2°F.	Correct to 1°F.
	$66\frac{2}{3}$ per cent. correct	75 per cent. correct	95 per cent. correct	75 per cent. correct	75 per cent. correct
°F.					
7·0	7·3	10·3	18·4	21·5	28·7
8·0	9·6	12·3	20·3	23·2	29·2
9·0	11·4	14·0	21·9	24·5	29·6
10·0	13·0	15·7	23·2	25·5	29·8
11·0	14·5	17·1	24·2	26·3	30·0

σ is the standard deviation of single temperature observations within the month and is probably about 90–95 per cent. of the standard deviation referred to a long-period mean.

An examination of actual data over Larkhill was made for a winter and for a summer month chosen at random. Table V shows for January 1942 and July 1947 at 900 and 200 mb. (*a*) the mean temperature at 1200 and the standard deviation σ within the specified month, (*b*) means of ten observations at three-day intervals with corresponding values of $|d|/\sigma$, (*c*) means of ten observations on consecutive days with corresponding values of $|d|/\sigma$. As above, d is the departure of the ten-day mean from the 31-day mean (given in (*a*)) and $|d|$ denotes the magnitude of d without regard to sign. For ten scattered

TABLE IV—PERCENTAGE NUMBER OF OCCASIONS WHEN A GIVEN ACCURACY (u°F.) IS ATTAINED WITH n OBSERVATIONS OF TEMPERATURE

Number of possible days in month = 31

Standard deviation	Accuracy (u)	Number of observations per month (n)						
		5	10	15	20	25	28	30
°F.	°F.	*percentage*						
7	1	13	17	25	34	49	68	93
	2	25	35	47	62	81	95	99·96
	5	58	74	88	97	99·91	(100)	(100)
10	1	9	13	17	24	36	51	79
	2	18	25	34	46	65	83	99
	5	42	57	73	88	98	99·95	(100)

observations (*b*) we expect $|d|/\sigma$ to equal or exceed $\lambda/\sqrt{10}$, and for ten consecutive observations (*c*) we expect $|d|/\sigma$ to equal or exceed $\lambda(3/10)$ for P per cent. of the values. There are 12 values of $|d|/\sigma$ in (*b*) and in (*c*) but each group of three is equivalent to only two independent values and so, to obtain the value equalled or exceeded by the largest $|d|/\sigma$ in (*b*) or in (*c*), we take for λ the value corresponding to 1 in 8, *i.e.* to $P = 12\frac{1}{2}$ per cent. so that $\lambda = 1{\cdot}52$. Considering the eight largest values in (*b*) and in (*c*), we find the following comparison between observed and expected values of $|d|/\sigma$

	$|d|/\sigma$ equalling or exceeding							
	(*b*)				(*c*)			
	0·21	0·28	0·36	0·48	0·37	0·49	0·63	0·83
number observed	4	3	1	0	4	3	2	0
number expected	4	3	2	1	4	3	2	1

or, taking the mean of each set of three values, *viz.*:—

(*b*) 0·16 0·21 0·27 0·08, and (*c*) 0·23 0·29 0·51 0·39, the comparison for four independent values is

	$\lvert d\rvert/\sigma$ equalling or exceeding (*b*)			(*c*)		
	0·10	0·21	0·36	0·17	0·37	0·63
number observed	3	2	0	4	2	0
number expected	3	2	1	3	2	1

The comparisons are reasonably good when account is taken of the smallness of the numbers of independent values.

TABLE V—MEAN TEMPERATURES AT 1200 G.M.T. OVER LARKHILL

	January 1942 900 mb.	January 1942 200 mb.	July 1947 900 mb.	July 1947 200 mb.
(*a*) Mean of 31 observations (°F.)	28·5	−63·7	52·6	−53·5
Standard deviation (°F.)	4·88	10·08	6·77	5·14
(*b*) Means of 10 scattered observations (°F.)				
days 1, 4, 7, . . . 28	29·6	−63·6	53·9	−52·8
days 2, 5, 8, . . . 29	28·0	−60·6	49·5	−53·8
days 3, 6, 9, . . . 30	27·7	−66·9	53·6	−53·7
Values of $\lvert d\rvert/\sigma$				
days 1, 4, 7, . . . 28	0·23	0·01	0·19	0·14
days 2, 5, 8, . . . 29	0·10	0·31	0·46	0·06
days 3, 6, 9, . . . 30	0·16	0·32	0·15	0·04
(*c*) Means of 10 consecutive observations (°F.)				
days 1–10	29·5	−67·6	47·0	−52·2
days 11–20	27·0	−61·3	53·1	−56·4
days 21–30	29·4	−61·4	56·9	−51·7
Values of $\lvert d\rvert/\sigma$				
days 1–10	0·20	0·39	0·83	0·25
days 11–20	0·31	0·24	0·07	0·56
days 21–30	0·18	0·23	0·63	0·35

Different hours of observation.—If the mean temperature aimed at is that found by taking observations at h different hours on each of the N days of an N-day month, the values of σ' (standard deviation of means of n observations) considered above will have to be increased to allow for variation of temperature during the day. Means based on one observation per day (all N days of the month), at different times of day, will have a standard deviation about the required mean (comprising hN observations) of σ_h, say, where

$$\sigma_h = \frac{1}{h}\sum_{r=1}^{h} M_r^2 - \left[\sum_{r=1}^{h} M_r\right]^2, \qquad \ldots (5)$$

M_r being the mean temperature, for the specified month, at the rth observation hour. We then have, for the standard deviation of means of n observations scattered through the month, and at divers hours,

$$\sigma' = \sqrt{\left[\frac{\sigma^2}{n} + \sigma_h^2\right]} \qquad \text{for } n \leqslant N/3 \qquad \ldots (6)$$

$$\sigma' = \sqrt{\left[\frac{3(N-n)}{2Nn}\,\sigma^2 + \sigma_h^2\right]} \qquad \text{for } n \geqslant N/3 \qquad \ldots (7)$$

At most levels in the upper air over Larkhill σ_h is small compared with σ.

METEOROLOGICAL OFFICE DISCUSSION

Rocket-sondes

The Discussion, held at the Imperial College on November 29, 1948, was on the high-altitude research work with V-2 rockets carried out in New Mexico by the U.S. Naval Research Laboratory. Mr. D. D. Clark opened the discussion which was based on the following five papers:—

Krause, E. H.—High-altitude research with V-2 rockets. *Proc. Amer. phil. Soc., Philadelphia, Pa.*, **91**, 1947, p. 430.

United States Naval Research Laboratory. Upper atmosphere research reports :—

I.—*U.S. naval Res. Lab. Rep.*, No. R-2955, 1946.

II.—*U.S. naval Res. Lab. Rep.*, No. R-3030, 1946, by H. E. Newell and J. W. Siry.

III.—*U.S. naval Res. Lab. Rep.*, No. R-3120, 1947.

IV.—*U.S. naval Res. Lab. Rep.*, No. R-3171, 1947.

Towards the end of 1945 the American Naval Research Laboratories began investigating the possibilities of the rocket-sonde. At the time the only suitable rocket available was the German V2 of which there were adequate supplies. As tests on these rockets were due to begin at the ballistics and ordnance testing ground at White Sands, New Mexico, in a few months' time, the opportunity was taken to combine these trials with the upper atmospheric research programme. In this way a delay of two to three years, pending the development of a suitable rocket, was avoided and experiments were able to begin almost at once.

The first trials were due to start three months after the formation of the rocket-sonde section, which meant that, with the limited time for preparation, much improvization was necessary. Firings took place about once every fortnight according to a programme arranged to expend all the stock of rockets before deterioration rendered them unserviceable. It was expected that development of the instruments and technique would take up most of the first year; however, progress was better than expected and results were obtained in many fields. Besides the Naval Research Laboratories other institutions took part in the experiments, including the Universities of Michigan, Princeton, Harvard, the Johns Hopkins University, the National Bureau of Standards and the Californian Institute of Technology.

Investigations covered the fields of solar spectroscopy, cosmic radiation, the ionosphere, and the pressure and temperature of the atmosphere. In solar spectroscopy interest centred on the absorptive properties of the atmosphere, including the ozone distribution, and on the intensity and nature of the solar ultra-violet radiation. From the study of cosmic radiation it was hoped to obtain first-hand knowledge of the primary particles as they enter the atmosphere. The ionosphere experiments were expected to furnish information on the ion density at intermediate points between the ionised layers and the measurement of pressure and temperature would give data which could be compared with existing knowledge.

Special instruments had to be developed to operate at the very low pressures and under conditions of vibration and acceleration occurring during the rocket's flight. The maximum height reached would be in the neighbourhood of 150 Km.

but the part of this flight during which observations were to be made lasted only some five minutes during which time the rocket was travelling at anything up to one mile a second. After the arrangements for taking the observations had been made there still remained the problem of recovering the data.

The V2 is 46 ft. long and 5½ ft. in diameter, it weights 28,000 lb. with fuel, 9,000 lb. empty, and has a pay load of 2,000 lb. For the experiments the former warhead was replaced by a new type specially designed to house the instruments. It normally contained various pressure and temperature gauges, the cosmic-ray counters and the electronic gear, which was housed in a pressurised case, also batteries and some ground controls. Behind the warhead is the control chamber in which are installed the control units for the rocket and the Doppler tracking equipment. The main body houses the fuel tanks, the pumps, and the motor. Three carbon vanes in the jet of exhaust gases from the motor stabilise the rocket during powered flight but when the fuel is exhausted the rocket may roll and yaw.

Aerials for the ionosphere experiments were attached to the tail and trailed behind during flight. Others were attached delta-wise to the rocket body and two tail fins. Occasional fading of the signals was experienced due to masking of the aerials by the exhaust jet or the rocket body.

The tail fin was chosen as the best site for the spectrograph, and cameras were mounted at mid points on the body to record the changes in orientation during flight.

The position and velocity of the rocket, which must be accurately known if the other observations are to be of any use, is obtained by Doppler tracking methods, by radar, and by optical telescopic theodolites. Of these the Doppler method and the theodolites were the most successful.

Two methods were used to recover records: telemetering to the ground and physical recovery of the recorded data after the flight. In the telemetering system the instruments are designed to present the observations in the form of representative voltages in the range 0–5 v. which are applied to control a pulse-emitting circuit so that the spacing between successive pulses is proportional to the applied voltage, thus producing a pulse time-modulated transmission. These signals are received at the ground station, where they are re-converted into characteristic voltages which are recorded photographically on an oscillagraph. The arrangement is such that a measurement is made and recorded for every 8 m. of flight path. The accuracy expected was ± 5 per cent. which was later improved to ± 1 per cent. The frequency of the 3 Kw. transmitter was chosen at 7,000 Mc./sec. to be high enough to penetrate the ionosphere and also to be clear of other frequencies in use.

The second method of recovery meant installing an automatically recording instrument which could stand up to vibration and accelerations of $6g$, and afterwards endeavour to recover the record after the flight. Recording in nearly all cases was performed photographically, the films being wound into steel containers after exposure. Unless the record is separated from the rocket before impact there is little hope of recovering anything. Separation was attempted using ejection mechanisms but most success was obtained by simply exploding the rocket, during its descent, into three pieces, the warhead, the main body and the tail section. The automatically recording instruments

which had been mounted in well-protected positions in their respective sections were then recovered in good condition.

Pressure measurements covered the range from 10^3 to 10^{-4} mm. of mercury which necessitated the use of several different types of instrument. The range from 10^3 to 10 mm. was covered by an ordinary bellows type of pressure gauge while, for lower pressures, gauges normally used in high-vacuum work were employed. The bellows gauge was one of the few instruments which incorporated a lever mechanism, the axis of the lever being mounted parallel to the axis of the rocket to avoid effects due to acceleration. A waxed thread from this lever was wrapped round the shaft of a micro-torque potentiometer thus converting movements of the bellows into rotations of the shaft and hence into representative voltages.

The presure range from 10 to 10^{-3} mm. was covered by Pirani gauges which consist of a filament of fine platinum or tungsten wire heated to about 200°C. by an electric current. At low pressures when the mean free path of the air molecules is comparable with the diameter of the filament, the thermal conductivity of the air is related to its pressure by the approximate formula $K = ap$ where K = thermal conductivity, p = pressure, a = a constant. If the current is kept constant then the temperature, and hence the resistance of the filament, vary with the pressure. This resistance variation is easily converted to a voltage variation. Two types of Pirani gauge were in use. A platinum filament of 0·007-in. diameter was used in the range 10 mm. to 0·1 mm. while a tungsten filament of 0·005-in. diameter was used for pressures from 10^{-1} mm. to 10^{-3} mm. With the platinum gauge the voltage variation over the range was 1 v. at 10 mm. to 3 v. at 0·1 mm. and with the tungsten filament the range was from 2·7 v. at 0·5 mm. to 5 v. at 0·01 mm. These voltages were fed through the commutator directly to the input of the telemetering system.

In the range of pressures from 10^{-3} to 10^{-5} mm. ionization gauges were used. In these gauges, electrons from a heated filament are accelerated towards a collecting electrode. The positive ions formed during their passage are collected on a third electrode. The resulting ion current varies with the pressure, the relationship being linear if the emission is less than 5 milliamps up to pressures of 10^{-3} mm.

A special type of ionization gauge was used in the V2 experiments, called the Philips gauge. In it the electron path is increased several hundred times by a magnetic field across the tube which causes the electrons to move in spirals. The resulting increased electron path increases the probability of electrons ionising molecules which gives a greatly magnified ionization current. With ionization gauges pressures are recorded instantaneously.

The point of the rocket is in the form of a cone, and pressure measurements are taken at the apex of the cone, on the sides of the cone and also at points on a circumference of the rocket near the tail section. The pressure of the surrounding air is derived from the pressure at the tip for heights up to 80 Km., by the application of the theory of planar shock waves as in the case of the pitot tube, but instead of the unknown being the velocity, it is the outside pressure. When pressure is measured on the sides of the cone then Taylor and Maccoll's theory of conical shock waves is resorted to in order to express the pressure in terms of the Mach number or, since the velocity is presumed known, in terms

of the absolute temperature. Another relationship is then sought between the pressure and Mach number (or absolute temperature) such as, for example, an empirical relationship from the wind-tunnel data on the V2, and the two equations then solved simultaneously for pressure and temperature. The outside pressure was also measured directly by making use of a particular property of the V2 as revealed by German wind-tunnel tests, namely that at a circumference on the body just in front of the tail section the pressure reads to within 10 per cent. of the surrounding air pressure and is insensitive to changes in attitude of the rocket. Although the wind-tunnel data referred to Mach numbers up to 2, it was assumed that this relationship held for higher Mach numbers as well. Two Pirani gauges mounted one on each side of the rocket in this position agreed within experimental error throughout the flight which showed that at higher Mach numbers the effect of yaw is still negligible. Pressure readings obtained in this manner were found to agree with those obtained from a radio-sonde ascent made at the same time and place except at the point where the rocket speed was about equal to the velocity of sound.

Above altitudes of 80 Km. the mean free path of the molecules begins to assume the dimensions of the rocket, while above 100 Km. the mean free path is much greater than the rocket's dimensions. In the region above 100 Km. the problem is treated statistically, and, by means of the Maxwell-Boltzmann distribution, a relationship is established between the pressure and temperature at the tip of the cone and the pressure and temperature of the atmosphere. An additional similar relationship is then derived for the pressure and temperature on the side of the cone. The pressure and temperature of the atmosphere at that point of the flight path is then obtained by solving these two simultaneous equations. No method is suggested for obtaining the pressure and the temperature in the region between 80 and 100 Km.

Temperature measurements are made at various points under and on the surface of the rocket for assessing the performance and finding the operating temperatures of the instruments. The gauges utilised were either platinum resistances, ceramic semi-conductors (thermistors) or else thermocouples, the output voltages from which were fed directly to the input of the telemetering set. Atmospheric temperature is either derived indirectly, with the pressure as indicated above, or else is calculated, up to 80 Km., from the slope of the pressure-altitude graph. Since the temperature is a derived quantity depending on measurements of velocity and pressure and the solution of certain approximate relationships, the degree of accuracy is not high and for one flight for which the probable error had been assessed it was given as ± 25°C. from 50 to 60 Km., ± 15°C. from 65 to 70 Km., ± 20°C. at 72·5 Km. and ± 40°C. above 100 Km. The general shape of the temperature-altitude graph agreed with that predicted by the National Advisory Council for Aeronautics from data already available from other sources. The accuracy of the observations in the troposphere agreed well with those obtained from a radio-sonde ascent. The main features of the temperature at high altitudes were the maximum of about 320°A. at 50 Km., the minimum of approximately 200°A. at 80 Km., and the steady rise above 100 Km. Other methods of direct measurement of temperature have been suggested and some have been tried but, up to the time of writing these reports no successful results had been obtained. The methods suggested included the detonation of explosives ejected from the rocket at

intervals of 10,000 ft. so that by measurements of the time lag between the visual puffs and the sounds of the explosions as measured at a point on the ground, the mean temperature between the 10,000 ft. levels would be found. Another ingenious suggestion was to eject grenades containing small pellets, which would explode, scattering the pellets, some of which should possess sufficient velocity to appear as artificial meteorites which could then be observed with cameras from the ground, and the air density and temperature deduced.

The spectral distribution of solar intensity at the earth's surface depends on the radiative characteristics of the sun and on the transmissive properties of the Earth's atmosphere. Owing to strong absorption by ozone and oxygen molecules, all the wave-lengths below 2900A are absent at the earth's surface and so the distribution in the ultra-violet is not completely known. To obtain measurements in the range 1100 to 2900A a height of 90 Km. has to be passed. The spectrograph used in these experiments employed some novel features. To avoid absorption of the ultra-violet rays no lens systems were used; instead, two lithium-fluoride beads having a wide angle of view, and replacing the conventional slit, were situated on opposite sides of the instrument. The beads, which passed all wave-lengths above 1100A, gave about 100 times more illumination at maximum than a slit and because of their wide angle of view and the alignment of the optical axes, recording was continuous no matter what the orientation of the rocket. The images of the sun from the two beads are reflected on to a concave mirror of 40-cm. radius of curvature on which a grating of 15,000 lines to the inch is engraved. The spectra from the two images are focused side by side on to a 35-mm. film which is wound by a small electric motor. Owing to astigmatism of the grating the point image of the sun produces a line spectrum on the film. Separate exposures are made, the shutters consisting of sector disks (one for each bead) which rotate continuously at constant speed behind the beads. Each time an exposure is made the film is arrested and a signal is transmitted to the ground station so that each photograph may be identified later. The film is finally wound into an armoured container where it is preserved until recovered after the flight. To photograph radiation of less than 2200A, which is absorbed in gelatine emulsions, the emulsion on the film is coated with material which absorbs ultra-violet light and fluoresces in visible and near ultra-violet radiation (any oil film will do this). With the aid of this spectrograph the curve of average radiant energy as a function of wave-lengths was extended from 2900 to 2200A. It was found that the ultra-violet intensity is much less than was predicted. A large number of fully and partly resolved absorption minima were observed between 2950 and 2300A, nearly all of which were blends of two or more closely spaced lines. The analysis of the line widths and intensities which are important in determining the excitation conditions in the sun is not yet complete.

The ozone distribution between two levels in the atmosphere is derived from comparison of the spectra at these two levels. The results generally confirm observations made by other methods. On one particular occasion, for example, maximum concentrations were found at 17 Km. and at 25 Km. Above 30 Km. the concentration decreased rapidly and vanished within experimental error at 50 Km. A graphical integration gave the total concentration as 2·7 mm. at standard temperature and pressure which agreed with other observations taken just before and just after the flight of 2·5 and 2·7 mm. respectively.

Methods at present in use to determine the ion density in the ionosphere give only the maximum values for each layer. It was hoped that with the rocket-sonde, direct measurements of the ion density at all points would be possible. Two radio frequencies were chosen, one of which was near to the critical ionospheric frequency for that day and the other an integral multiple of this frequency. The lower frequency signal will be retarded by the ionised layers while the higher frequency will be unaffected. If the two frequencies are emitted simultaneously from the rocket and received at the ground station, then, if the lower frequency is multiplied by the integral quotient of the two and compared with the other it will be found that passage through the layers of the ionosphere has resulted in a phase shift between the two. After making the required corrections for Doppler effect and instrumental changes it was hoped to be able to deduce the ion density at all points of the flight path. At the time of writing the reports, the analysis, which is very complex, had not been completed.

A considerable number of the experiments were taken up with cosmic radiation investigations with a view to determining both the nature of the primary radiation and to studying the fundamental reactions which take place as the primaries pass through the atmosphere. Geiger-Müller counters were employed to detect the rays owing to the ease with which the counts could be telemetered. Absorption tests were made with lead thicknesses of 2, 4, 6, 12 and 14 cm. It was found that 35 per cent. of the rays were stopped in the first 4 cm. of lead; therefore, at least this portion was not primary. It was suggested that these were electrons which arose from the atmosphere below due to meson decay and spiralled round the Earth's magnetic field lines. The remaining 65 per cent. penetrated 4 cm. of lead, some producing showers. From the percentage penetrations of the other thicknesses of lead it was deduced that if all the radiation penetrating 6 cm. was primary then the electron component, on the basis of shower production, was not more than a maximum of 14 per cent. of the primary, while the non-electronic component penetrating 12 cm. was 68 per cent. of the primary and that absorbed in 12 cm. was 18 per cent. of the primary. Also the ratio of total radiation in free space to that at sea level was 11·5 : 1 while the ratio of the hard component in free space to that at sea level was 9 : 1.

In addition to measurements recorded and telemetered, interesting photographs of the Earth have been taken from the rocket at high altitudes. The experiments with rocket-sondes are still in progress, other types of rocket have been developed and are now in use, the instruments and methods described above are being constantly modified and improved upon. What is encouraging is that in all the fields which were investigated results of greater or less importance have been achieved. Although the importance of the rocket-sonde in investigation in the upper atmosphere is recognised it is still a research instrument whose present high cost of operation will confine its use to investigations of a special character for many years to come.

The Director, in opening the discussion, said that the effort and industry put into these trials is to be admired as well as the way in which methods and instruments usually associated with the research laboratory have been adapted and employed in these experiments. The photographic results have been good and the temperature results for the upper atmosphere are very interesting. He asked the following questions:—

Has anyone any explanation of the double maximum in the ozone distribution curve ?

Has the upper minimum in the temperature curve ever been repeated ?

How were the estimates of the errors in the temperature readings obtained ?

Is there any information on air density or composition of the air ?

Dr. Harrison thought that one possible explanation of the double maximum in the ozone distribution is that ozone having a higher molecular weight than oxygen may tend to diffuse downwards. It has been suggested that ozone affects the performance of radio-sonde balloons. He asked:—

Why was the radar tracking found to be unsuccessful ?

Is the null point of the pressure from the wind-tunnel experiments dependent on the air density and, if so, what result would that have on the measurements ?

Mr. Absalom said more temperature observations were required both by day and by night. The shape of the temperature-height curve is systematic; low temperatures of 100°A. at 80 Km. have been reported in a paper by Seaton.* According to Regener the fundamental layer in the ozone distribution is the upper maximum, the lower layer being caused by transport of ozone from lower latitudes.

Dr. Robinson said that in his recent paper* Seaton claimed that differences in temperature at 100 Km. of 500°A. between 40° and 20° latitude occurred at the same time. The null point method of pressure measurement on the rockets is not very satisfactory. Was the temperature-height curve from the rocket data based on more than one ascent ?

Have temperatures been taken at night ?

Has any laboratory work been done on the wind-tunnel tests of shock wave theory for low pressures ?

Professor Stratton asked if the attempt to produce artificial meteorites met with any success.

Mr. Weeks said the measurement of ion density by the phase-shift method does not take into account the effect of the Earth's magnetic field and the polarization of the emitted rays.

Dr. Scrase asked if any attempt had been made to take samples of the atmosphere and, if so, how was it done ?

Cdr. Frankcom said the ocean weather ships regularly take observations on meteors; would it be possible to observe artificial meteor showers from ships and would it be of any use ?

Mr. Ashford pointed out that Pirani gauges have a time constant which would be important on a rocket travelling at high speed. Are there any figures on the lag of the Pirani gauges used in these experiments ?

Is the gap in temperature and pressure data between 80 and 100 Km. due only to the lack of a suitable method of extraction or were observations not taken over this interval as well ?

How many measurements can be made in one ascent ?

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*SEATON, S. L.; State of the upper atmosphere. *J. Met. Lancaster, Pa.* 5, 1948, p. 204. [In this paper Seaton calculates temperature from radio observation of the rate of recombination of the ions.—Ed. *M.M.*]

Mr. G. Oddie asked has it ever been tried to launch the recording equipment from the rocket at the top of its flight and let it descend by parachute? The very high impact speeds of the rocket would then be avoided.

Mr. Clark stated in reply that the diffusion theory was probably correct in the explanation of the double maximum in the ozone layer. Double maxima had been found before by Götz. The ozone was formed in the upper layers, probably at 50 Km., and so the presence of the second maximum must be explained by either diffusion or transport from other latitudes. The rate of formation and dissociation of the ozone may also come in.

The temperature figures given referred to one particular ascent; it was not known if the second minimum in the temperature curve had been repeated in later flights but the presence of that minimum is generally accepted and is given in the latest estimate of upper atmospheric temperatures published by the National Advisory Committee of Aeronautics, Washington, D.C. It has also been confirmed by Fred Whipple's work on meteors and is given by some authors as the explanation of the existence of noctilucent clouds observed at this altitude. The estimates of the errors in temperature have not been given in detail in the reports but it can be assumed that they were based on the sum of the instrumental and electronic errors of all the measurements required for their determination.

No attempts were made to measure air density directly. Some attempts were to be made to take samples of the air to investigate the composition of the atmosphere.

The failure of the radar method of tracking is not made clear in the reports.

The null point method of obtaining the pressure was based on wind-tunnel experiments made in Germany. So far as is known these tests were not extended to cover low densities, so that the use of this method in the rocket-sonde experiments is based on the assumption that this relationship holds also at low densities.

No successful ascents had been made at night up to the date of writing the reports nor is there any mention in the reports of any laboratory confirmation of the shock-wave theories for low pressures. As regards the artificial meteors, grenades have been launched successfully and exploded but the fragments have not so far been observed.

A method for taking samples has been mentioned and has no doubt since been tried. A long-necked bottle which has been evacuated is opened at high altitude by breaking the neck and then resealed by compressing and soldering a metal part of the neck.

The Pirani gauges used had a lag of 1·5 sec. which is equivalent to 2-Km. path length at 60–80 Km. The data incorporate this correction.

Observations were made continuously; the gap from 80–100 Km. is no doubt due to the lack of a reliable method of extraction.

Measurements can be made and transmitted at 200 a second; the total number depends on the length of the flight subject to instrumental failure.

No attempts have been made to launch the equipment from the rocket on a parachute apart from recovery trials.

ERRATUM

January 1949, PAGE 20, last line; *after* 400 mb. *add* and -16°F. at 200 mb.

[To face page 76

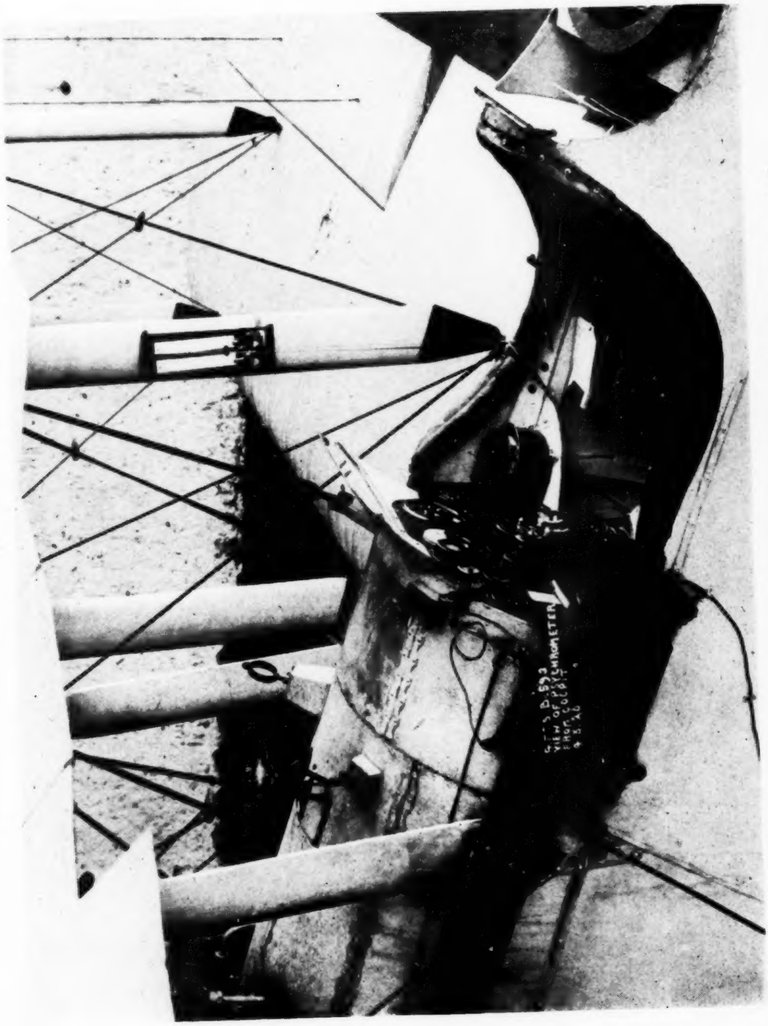

FIG. 1—STRUT PSYCHROMETER MOUNTED ON AN AIRCRAFT IN 1926

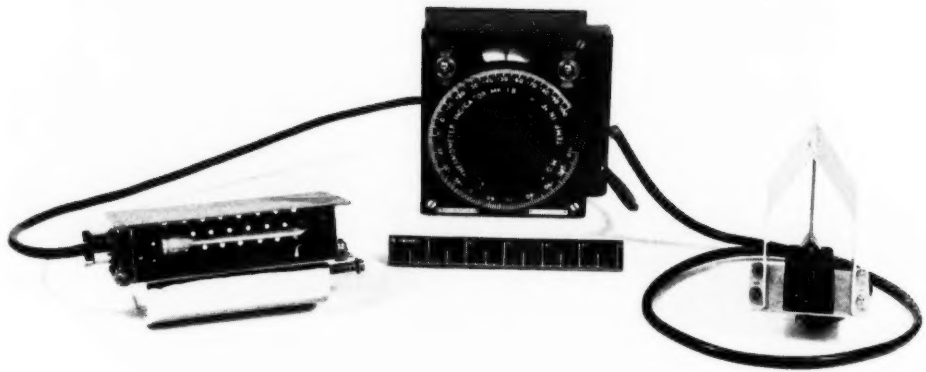

FIG. 2 ELECTRICAL RESISTANCE THERMOMETER
(see p. 84)

(see p. 84)

FIG. 3—ELECTRICAL RESISTANCE THERMOMETER MOUNTED ON A BOSTON
(see p. 84)

To face page 77]

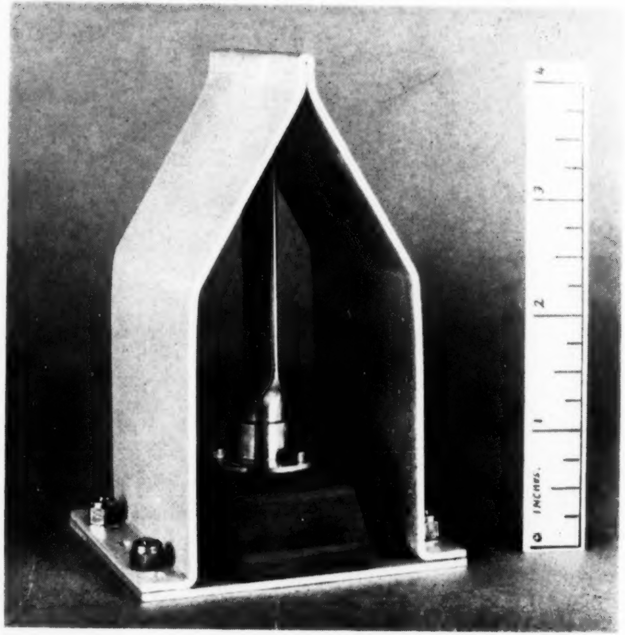

FIG. 4—DRY BULB OF THE ELECTRICAL-RESISTANCE THERMOMETER

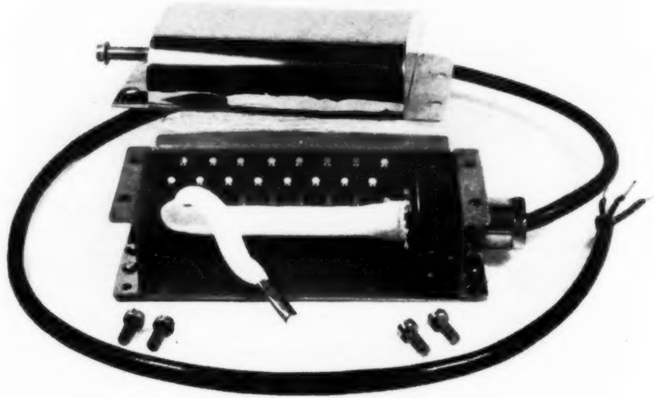

FIG. 5—WET BULB OF THE ELECTRICAL-RESISTANCE THERMOMETER

METEOROLOGICAL RESEARCH COMMITTEE

The fourth meeting of the Instruments Sub-Committee was held on January 20, 1949. The Committee considered reports on the application of the chronometric principle to radio-sondes and decided to pursue alternative lines of development. The future lines of development of measurement of upper winds by radar methods were also discussed and a general policy agreed. The instrumental part of the research programme was reviewed and recommendations for changes were formulated.

The fourth meeting of the Synoptic and Dynamical Sub-Committee was held on January 27, 1949, the business of the Committee being mainly concerned with proposals for the amendment of the Research Programme. A paper by Dr. A. H. R. Goldie, "Measure of atmospheric circulations" (*Met. Res. Publ.*, No. 428), was also considered.

The fifth meeting of the Physical Sub-Committee was held on February 3. The primary business of the meeting was consideration of amendments to the appropriate part of the research programme. A paper, *Met. Res. Publ.* No. 452, on the size distribution of raindrops was also considered.

OFFICIAL PUBLICATIONS

The following publication has recently been issued:—

Instructions for the preparation of weather maps, with tables of the specifications and symbols

This publication contains instructions for decoding and plotting weather messages giving surface observations from land stations and ships. The instructions are based on the system of plotting adopted at the International Meteorological Conference at Warsaw in September 1935, with such amendments are are necessitated by the introduction of the new codes approved by the Conference of Directors at Washington in September 1947.

The illustrations and tables include reproductions of all the symbols used for plotting station and ship reports, fronts and weather areas, together with specimen plottings. The relevant symbolic forms of codes and tables of specifications (reproduced from the "Handbook of weather messages, codes and specifications", Parts II and III) are given in an Appendix. The publication thus provides, in concise form, all the information required for plotting surface charts, according to the practice of the Meteorological Office.

ROYAL METEOROLOGICAL SOCIETY

Discussion on post-glacial climatic change

At the joint meeting of the Society with the Royal Astronomical Society held at the Science Museum on December 15, 1948, a discussion took place on post-glacial climatic change.

The discussion was opened by Mr. Hoyle who considered the possibility of variations in solar radiation, Dr. H. Godwin of the British Ecological Society who outlined the biological evidence of climatic change, Professor Manley

speaking on fluctuations of climate shown by instrumental and other records in the past 200 years, and by Dr. C. E. P. Brooks who gave a comparison of the evidence from numerous sources with a general discussion on the meteorological aspects.

Mr. Hoyle, pointing out that the earth's mean temperature depends upon its distance from the sun and the sun's radiation, said that, according to astronomical theory, if the sun were left to itself it would very slowly increase in brightness while there was no evidence of any significant change in the distance of the earth from the sun in the last 10 million years.

However, the sun was not left to itself because there was a very great deal of interstellar gas aggregated locally into " clouds ". As the sun passed through a cloud it would capture some of the gas which would have the effect of appreciably increasing its ultra-violet radiation. This theory, due to Hoyle and Lyttleton, had been recently confirmed by observations of the spectra of dwarf stars in regions known to contain the necessary " clouds ". The solar ultraviolet radiation is absorbed in the upper layers of the atmosphere and Mr. Hoyle suggested that a substantial increase in its intensity, such as would occur when the sun passes through a cloud of interstellar gas, would produce a profound disturbance in the state of the atmosphere which might well be connected with the long-period changes in climate over millions of years.

Dr. Godwin said much of the biological evidence for climate change was based on the analysis of tree pollen. He gave diagrams showing the densities of pollen of various trees, from the warmth-loving lime to the birch which preferred a cold environment, found in the deposits in Hockham Mere, Norfolk. These deposits showed the late glacial tundra, the well-known Atlantic warm period from 6000 to 3000 B.C. and the cold wet period which set in suddenly about 500 B.C.*

Dr. Godwin went on to point out that though biologists must supply much of the evidence for climatic change they are not sure to what extent species are in equilibrium with the climate. In this connexion he described the interesting work of Iversen† on the climatic control of the development of the mistletoe, holly and ivy. This worker plotted on scatter diagrams, having the mean temperature of the warmest and coldest month as ordinate and ab cissa, the state of development reached by these three plants at a number of meteorological stations in Europe. On these scatter diagrams called " thermospheres " it was possible to draw curves delimiting temperature régimes in which the plants were able to reach various stages of development (grew but no flowers, flowered, etc.).

It was satisfactory to note that similar curves plotted from pollen analysis of deposits at a station in Denmark gave past temperature régimes agreeing with other evidence.

Professor Manley opened his remarks by pointing out that the instrumental long-period records, those for temperature in north-west Europe are available from A.D. 1706, may give the key to past changes. The accordance between trends shown by the recently reduced Swedish, Dutch and British records is sufficient to lead to a certain confidence on the results they show. These can

*see BROOKS, C. E. P.; Unsolved problem of climatic change. *Met. Mag., London*, **76**, 1947, 128.
†IVERSEN, J.; Viscum, hedera and ilex as climate indicators. *Geol. Fören. Stockholm Förh.*, **66**, 1944, p. 463.

be related to behaviour of Scandinavian and Icelandic glaciers, which vary primarily with temperature, and their greatest post-glacial advance culminated about 1750 (sometimes 1850); since when retreat has prevailed. In north England and Sweden the last 100 years have seen an appreciable overall rise in winter temperature; summers bring little changes. Ångstrom has interpreted this as due to " increased vigour of the circulation ". It is still uncertain whether this is world-wide and whether an extra-terrestrial agency must be invoked.

This " little ice age " culminating about 1750 apparently began in Iceland with a deterioration about 1300, similar in character to that of 500 B.C. referred to by Dr. Godwin. Adopting as a working hypothesis that the prevailing vigour of the circulation changes rather rapidly from time to time both the above deteriorations may be explained as due to increased vigour accompanied by a spread of the Arctic ice and its melt water. Whereas the present-day amelioration is also associated with increased vigour but a decrease in the extent of the sea ice. This and other data suggest that if this working hypothesis is used the spread of the sea ice must be regarded as an independent variable, dependent on other factors which he hoped the oceanographers would elucidate.

If glacier variation depends so largely on the length of the ablation season it should be closely associated with variations of spring temperature; if these are put in 10-yr. running means the results are certainly agreeable and point again to the probable effect of the spread of Arctic sea-ice on the temperature of polar maritime air. Instrumental records suggest that tropical maritime air in winter has had much the same temperature throughout.

Earlier variations in summer mean temperatures required by Iversen for Denmark, and also those shown by the late glacial Alleröd oscillation, are of the same dimensions as those shown by the decadal values of the present record. The vigour of the circulation hypothesis is capable of satisfying them all, while the spread of the melt water governs the " pitch " (50°F. Alleröd, 60°F. today), around which oscillations occur. Perhaps we should explore further to see why this " vigour " should be changes not merely for a decade, but for several centuries; and what relationship if any this all bears to solar radiation. Possibly this is another aspect of the warm anticyclone problem.

Dr. Brooks showed a composite diagram which was more qualitative than quantitive and which included all the data that he could get hold of. The period about 6000 B.C. to 3000 B.C. after being decidedly cold and ameliorating with cold winters and hot summers was warm—the climatic optimum; such a period could be explained astronomically, by a greater tilting of the earth's axis, for instance. Also the Baltic Sea would be more open after about 4000 B.C. so that in north-west Europe (on which the data were based) one had to consider a compromise between solar radiation and lower sea level.

However, the same climatic change seemed to occur over the whole of the northern hemisphere which could only be explained terrestrially by Arctic-ice conditions. Arctic ice does not explain the climatic optimum which must therefore depend upon solar radiation.

Dr. Brooks had reproduced a number of curves of sunspot frequency, thunderstorm frequency, auroral frequency, rainfall in south Russia (based on mud thicknesses in a small lake), and tree-ring thicknesses (of sequoias in California). He showed that there was some agreement between them but it

was not very good. The rainfall curve showed a maximum about the time of the climatic optimum which must therefore be a period of increased solar radiation. From about 1000 B.C. Dr. Brooks showed that the temperature was decreasing as the rainfall increased; he thought that Petterssen's explanation—the changes being due to changes in tidal force—quite good. More warm water in the arctic would mean a wet period in the northern hemisphere which would tend to break the ice cap. This drifting south would cause stormy conditions; as the ice retreats the summer would be dry as in 1921.

In conclusion Dr. Brooks thought the shorter variations (periods of the order of a century) could be explained by solar-radiation changes. Very short changes of the order of a decade were, in his opinion, due to nothing at all; he had plotted overlapping means from random numbers and obtained curves precisely similar to the 20-yr. moving means of temperatures in London. We should not therefore attempt to explain the small-period variations.

During the discussion which followed the following points were raised:—

Could Hoyle's theory explain short-period variations? Mr. Hoyle said it could if there were local variations in the gas clouds. The biological evidence might be affected by widespread plant disease. The sea-bottom sediment cores recently obtained should be analysed for evidence of climatic change. Mr. Schove explained the possibilities of using the written records of China which go back to 500 B.C. as given in his article in this magazine.*

ROYAL GEOGRAPHICAL SOCIETY

On January 24, Professor C. G. Rossby, Professor of Meteorology in the Universities of Chicago and Stockholm, lectured to the Royal Geographical Society on "Circulation patterns of the free atmosphere; their geographic and climatic implications".

Professor Rossby opened his lecture by stating that Professor Willett of Massachusetts Institute of Technology had shown in a report, to be published shortly, that both the long-term climatic variations in post-glacial times and short-term fluctuations in weather are associated with a contraction or expansion of the circumpolar vortex. Contraction of the vortex gives strong westerly winds and positive temperature deviations while expansion gives a weak westerly circulation, negative temperature deviations, greater frequency of north and south winds.

Rossby said his own connexion with the subject dated from 1936, when he was asked by the U.S. Department of Agriculture to investigate the meteorology of the droughts of 1934–36, and in this investigation he had to get rid of the small perturbations and try to get at the controlling factors deciding what tracks should be followed by the rain-bearing disturbances. This had been done by drawing mean surface-pressure charts for 5- or 7-day periods which were classified as high circulation-index pattern corresponding to Willett's contracting vortex and low index corresponding to the expanding vortex.

With the much increased upper air information available during and since the war, it became possible to construct charts of flow in the free atmosphere, which gave a hydrodynamic smoothing of the perturbations, as distinct from the statistical smoothing of the mean surface-pressure charts. These free-atmo-

Met. Mag., London, **78**, 1949, p. 11.

sphere charts, mostly contours of the 500-mb. surface, showed the existence of large wave-shaped patterns in the upper flow superimposed on the general westerly circulation. The waves of these patterns were much longer than frontal " waves ". A slide of the chart for October 9, 1945, showed 5 waves and the one for October 19, 1945, 3 waves. A feature emphasised on these charts by Professor Rossby, was the marked tendency for crowding together of the contour lines along a belt with an open pattern to north and south. The chart for January 10, 1947, shown next, gave also the isotherms on the 500-mb. surface showing that these were concentrated along the same belt as the concentration of contours. Next was shown a cross-section of the atmosphere from Thule (north Greenland) to Havana on the same day, in which the concentration of westerly wind along a narrow belt was well marked. In the concentrated flow—the " jet stream "—the speed was 90 m./sec. with a rapid decrease in speed to north and south. Professor Rossby said he had recently read a discussion between air navigators and meteorologists in which no reference had been made to this most important problem of the location of jet streams which, with velocities which might reach 150 m./sec., were of the utmost importance in air navigation, as the U.S. Air Force had found in bombing Japan after flying from the Marianas at 30,000 ft. The earlier view had been that the westerly flow was roughly linear in latitude, but it was clear from these charts that that was by no means the case.

Returning to the steering of surface disturbances by upper flow patterns, Professor Rossby showed the mean 500-mb. contour chart for February 6–12, 1948, with a chart of the tracks traversed by the surface disturbances, which followed very closely the direction of the upper flow pattern. During this period 8 low-level disturbances followed much the same track without breaking down the upper air flow pattern, which thus appeared to be uncontrolled by the low-level disturbances.

Turning to the changes which take place in the upper air pattern, Professor Rossby said that the breakdown of the " westerlies with waves " pattern generally occurred by northward surges of warm air, until the cold southward extending troughs were cut off and left as cold cyclonic vortices until finally dissipated. Conversely the anticyclonic warm northward tongues can be cut off by cold air surging to the south.

As an example of these phenomena, he showed the charts of February 12 and 20, 1948. On the 12th there was a strong westerly circulation, and on the 20th the westerlies had stopped, there was high pressure in high latitudes and a depression over France. This change was shown by coloured charts of warm and cold areas at 500 mb. to have been connected with a northward surge of warm air over the Atlantic which broke down the " westerly " circulation so that low-level disturbances were no longer steered across the Atlantic. This effect was referred to in the U.S.A. as a " blocking action ". As the " blocking action " developed, a " high " contour line of the 500-mb. surface advanced steadily westwards.

Similar effects, leading to the very cold weather of January–February 1947, were illustrated with 700-mb. contour charts. The charts showed an initially strong polar cyclonic vortex followed by a divergence of contours, " blocking action ", development of an anticyclone in very high latitudes, shifting of storm tracks well to the south and cold easterly winds over western Europe.

Among the points raised in the discussion (to which Sir Nelson Johnson, Mr. Gold, Professor Manley, Professor Miller, Mr. Bonacina and Mr. H. H. Lamb contributed) were means of foreseeing the development of jet streams; why, if post-glacial climatic variations were associated with the circulation index, the index should have remained much the same for thousands of years; the source of the energy of the upper air movements; and the influence of topography on the place of cutting off the cold pools. In reply Professor Rossby said there was a possibility of foreseeing the development of jet streams and advocated the placing of ocean weather ships in the best places for locating them; that the energy of the upper air movement must be provided from below, in some way not yet understood, by interaction between different air masses; and that there was a definite geographic control on the cutting off of cold pools, as there were three regions of maximum variability two of which were geographical and the third dynamically fixed from the first two.

ROYAL UNITED SERVICE INSTITUTION

Meteorology in war

The increasing importance of early consultation with the meteorologist in planning operations, particularly air operations, was stressed by the Director of the Meteorological Office in the course of a lecture given in London on February 2 to the Royal United Service Institution.

Speaking of the future, the Director said: "At the enormous speeds which are now becoming possible, the weather conditions become more critical. The meteorologist must aim at providing forecasts of increased accuracy and it is also clear that he will be required to forecast the conditions at greater heights than in the past.

" If long-range rockets are used, the heights to which meteorological information is required will be greater still.

" The meteorologist must also expect to be asked to forecast farther ahead than the 24 hours which is his present normal range. Research to this end is in progress both here and in other countries, but it would be wrong to hold out any hope of an early prospect of being able to forecast developments more than a few days ahead. Even if forecasts for three or four days ahead become possible, the predictions are likely to be in broad outline and not in detail. There is at present no prospect of being able to forecast weeks or months ahead.

" The demand by the Services for information about the conditions in the upper atmosphere coincides with what the meteorologist wants for the scientific study of his subject. It is now recognised that observations made at ground level will not take us very far, and that a full understanding of the events taking place in the atmosphere can be looked for only by a three-dimensional approach to the problem."

After referring to the effect on operations of different meteorological factors, Sir Nelson Johnson said that it was difficult to over-emphasise the importance of bringing the meteorologist into consultation right at the start of planning an operation.

He then went on to describe some of the technical aids to forecasting, pointing out that reports from the Atlantic are the most important for western European forecasting The Germans, for instance, made floating buoys consisting of a steel tube 30 ft. long and 20 in. in diameter, surmounted by a 25 ft. high tubular aerial. These buoys sent out, automatically, by radio, every six hours, readings of

barometric pressure, and air and sea temperatures.

British methods of obtaining Atlantic weather reports included weather flights gathering information from near sea level to 18,000 ft. The positions of distant thunderstorms were plotted with the aid of radio direction finding and four such observing stations (in Bedfordshire, Cornwall, Northern Ireland and Scotland) are still functioning. The radar method of wind finding was evolved for giving wind speed and direction all the way up to 60,000 ft. within an hour. The radio-sonde was developed, consisting of a balloon and instruments which automatically signal readings of pressure, temperature and humidity in the stratosphere. By these means upper air charts, similar to ground level charts, can be drawn for 10,000 ft., 18,000 ft. and 30,000 ft.

Such charts not only permit forecasts being made of the conditions aloft, but assist in the making of accurate forecasts of the weather to be expected at the ground. These wartime advances are now standard practice.

Before closing his address with a reference to the future, Sir Nelson described the meteorological organization in war.

We await with interest the full report of the lecture and discussion to be published in the *Journal* of the Institution.

LETTER TO THE EDITOR

Pressure anomalies at Gibraltar and in the vicinity

The article by Dr. Lee, "Anomalies of barometric pressure at coastal stations"*, is of interest, especially the concluding paragraph "that anomalies of 2 mb. or more are associated with landward winds". This type of anomaly in the pressures in this region is well known, but the pressures are only anomalous in that it is impossible to derive an accurate gradient wind from them. It is not possible at the present time to undertake a large-scale investigation but the pressure difference between Gibraltar and Larache (Spanish Morocco), 80 miles south-west of Gibraltar on two occasions in October 1948 is of interest.

At 1200 on October 3 the mean-sea-level pressure at Larache (20 ft. above mean sea level) was 1015·9 mb. and at Gibraltar, North Front (8 ft. above mean sea level), was 1020·5 mb. giving a "gradient wind" of 110° 74 kt. between the two places. The ascent at Gibraltar at 1345 gave winds of 100° 28 kt. at 950 mb. veering to 160° 7 kt. at 750 mb., and to 180° 17 kt. at 550 mb.

At 0600 on October 9, the mean-sea-level pressure at Larache was 1018·0 mb. and at Gibraltar, North Front, 1019·2 mb. giving a "gradient wind" of 110° 1; kt. between the two. The ascent at Gibraltar at 0800 gave winds of 100° 23 kt. at 2,000 ft. backing to 040° 17 kt. at 8,000 ft. and to 360° 20 kt. at 16,000 ft.

There is high ground rising to 6,000 ft. east of Larache; on the 3rd Larache lay in a trough in the lee of the high ground; on the 9th as the winds aloft backed with height, Larache did not lie in a lee trough and hence the gradient wind obtained from the mean-sea-level pressure difference between Larache and Gibraltar was similar to the 2,000 ft. wind at Gibraltar.

If it is desired to smooth out these anomalous pressures a pressure which can be taken as normal must first be found. This pressure cannot be the one at Gibraltar, North Front, for as Mr. Illsley has pointed out the pressures on Gibraltar are really irregular. The observing station at Windmill Hill (392 ft. above sea level) lies two and a half miles south of that at North Front, yet with easterly surface winds the sea-level pressure at Windmill Hill is on the

Met. Mag., London*, **77, 1948, p. 201.

average higher than at North Front. That this is not due to an error in correcting the observed reading is shown by the fact that with westerly surface winds the sea-level pressure at Windmill Hill is on the average lower than at North Front.

The table below shows the mean of the sea-level pressures at 1200 G.M.T. at both places for easterly and for westerly surface winds over the two months July and August 1947.

	North Front		Windmill Hill	
	E. winds	W. winds	E. winds	W. winds
Mean pressure (mb.)	1016·1	1015·0	1016·6	1014·9
Number of occasions	31	31	31	31

H. H. ASLETT

Gibraltar, November 10, 1948

NOTES AND NEWS

Meteorological Office aircraft electrical-resistance thermometer

In the days of slow-flying aircraft, air temperatures, wet and dry bulb, were read from a strut psychrometer of the type shown in Fig. 1, facing p. 76; the strut psychrometer consisted of large spirit-in-glass thermometers mounted in a wooden frame with a scale large enough to be seen from 10 ft. away, since the instrument was normally carried on a biplane, strapped to an inter-wing strut. With the advent of fast monoplanes, the strut psychrometer became obsolete because of its awkward shape and size and large air resistance. To replace it a new type of thermometer was designed which would have a small air resistance, be distant-reading, be easily fitted to aircraft with pressurised cabins (the mercury-in-steel thermometer is at a disadvantage here) and be accurate to within half a degree centigrade. The Meteorological Office aircraft electrical-resistance thermometer, which was designed by A. W. Brewer while with the Meteorological Research Flight during the war, satisfies all these requirements. This thermometer is shown between pp. 76 and 77 in Fig. 2 as both dry and wet bulb, and mounted on an aircraft in Fig. 3. The thermometer element which appears on the right of Fig. 2 and in Fig. 4 has a platinum resistance wire wound on a mica former which is made up of three thin mica sheets pressed together, two thin copper strips which serve as terminals being sandwiched in between. The former with the platinum resistance wire is then covered on both sides with two more mica sheets and inserted into a flat brass sheath which is mounted on a bakelite terminal block on a base plate so that the flat surface is parallel to the direction of flight when in position. A radiation shield, which also acts as a support for the thermometer at its extremity, protects the element on both sides. The element can also be adapted for use as a wet bulb by mounting it in a wet-bulb housing as shown on the left of Fig. 2 and in Fig. 5.

The principle of the resistance thermometer depends on the change of resistance in the platinum element with changes in temperature, the relation being almost linear. Together with the ballast resistance, contained in the terminal block, the platinum element in this thermometer has a fundamental interval of 40 ohms.

The resistance is measured by a Wheatstone bridge, having compensating leads in the three-wire system, which is contained in a box $4\frac{1}{2}$ in. × 5 in. × $2\frac{1}{2}$ in. suitable for mounting in the cockpit of single-engined aircraft. This part is shown in the centre of Fig. 2. The galvanometer, whose indicating needle can be seen in the inset on the face of the instrument, is connected to a sliding contact which is moved over a nichrome resistance wire, stretched round the circumference of an insulating disc, until a balance is found. The contact is moved by rotating the large knob, which can be seen on the front of the instrument, and which is geared in the ratio 9 : 1.

The scale, which covers a range from −110°F. to +100°F., is engraved on a circular dial of 4-in. diameter which rotates with the sliding contact against a single fiduciary mark engraved on the instrument face. At the lower temperatures 1°F. corresponds to about 1·1 mm. of scale while at the higher temperatures the correspondence is 1°F. to approximately 2 mm. of scale. The accuracy demanded of the instrument is ± 1°F. ($\frac{1}{2}$°C.) which requires that the scale be read to ± $\frac{1}{2}$°F. ($\frac{1}{4}$°C.) which is possible with this scale over the whole range.

The instrument is robust and can withstand vibration but extremes of cockpit temperature can affect the accuracy of the bridge; such extremes, however, are rare in modern aircraft.

Before the true air temperature can be determined a speed correction has to be applied to the readings.* This correction arises through the generation of heat in the boundary layers due to the motion of the thermometer through the air which is communicated as a rise in temperature to the thermometer. The heat thus generated consists of two parts—the part due to adiabatic rise in pressure and the part due to dissipation in the surface layers.

A balance is struck between the heat gained in this manner and the heat lost by conduction through the boundary layer. If the thermometer is shaped like a knife blade cutting into the wind the pressure term can be neglected and the equation of motion of the air can be solved by a method first indicated by Pohlhausen† giving the temperature of the "flat-plate" as

$$T = T_0 + \Delta(\sigma)$$

$$\text{where } \Delta(\sigma) = \frac{u_0^2}{2Jc_p}\sigma^{\frac{1}{2}} \text{ very nearly}$$

u_0 = speed of airflow (true speed of the aircraft)
J = mechanical equivalent of heat
c_p = specific heat of air at constant pressure
σ = Prandtl's number

This formula has been verified experimentally by Hilton.‡

Besides the advantage of an easily calculable speed correction, the "flat plate" offers small resistance to the airflow and is not adversely affected by icing or by rain as is, for example, the thermometer in which the temperature rise is due solely to the adiabatic pressure increase, *e.g.* the thermometer mounted inside a pitot tube.

**see* "Meteorological Air Observers Handbook", 1945, p. 14.
†POHLHAUSEN; *Z. angew. Math. Mech., Berlin*, **1**, 1921, p. 115.
‡HILTON, W. F.; Thermal effects on bodies in an air stream. *Proc. roy. Roc., London*, A, **168**, 1938, p. 43.

This thermometer has now undergone prolonged flight tests and has proved to be highly satisfactory. It compares favourably with the older type of strut psychrometer, except in one point—the lag—which is about the same for both but which is open to improvement by modifying slightly the design. Flight tests show the speed correction to be $1 \cdot 7 \, (V/100)^2$ in degrees Fahrenheit where V is the true air speed in knots.

A later modification made in stainless steel for increased rigidity is about to appear. It will be used in the wet-bulb housing where its increased strength is required.

D. D. CLARK

REVIEWS

Einführung in die Bioklimatologie, by Hellmut Berg, 8vo, 8 in. × $5\frac{3}{4}$ in., pp. iv. + 131, *Illus.*, H. Bouvier u. Co., Verlag Bonn. Price: *DM.* 7.50.

Hitherto the literature of bioclimatology has consisted of a very large number of original papers and a few encyclopædic works on special portions of the subject. Professor H. Berg of the University of Cologne in his new introduction to bioclimatology for meteorologists, has set out to meet a very real need for an elementary work on the whole subject.

Professor Berg takes a very broad view of bioclimatology, which he defines as concerned with the direct and indirect effects and interactions of the meteorological elements on life. Thus he naturally discusses the special climate of crop fields and forests as well as the effects of meteorological factors on plant life. Not quite so obviously, perhaps, he includes the climate of cities in bio-climatology as well as the effects of weather on man.

The book is divided into seven main sections:—

- A. Radiation as a bioclimatological element
- B. Climate of the layers of air next the ground, between the plants and in forests
- C. Agricultural meteorology and phenology
- D. Town climate
- E. Climate of dwelling rooms, factories, and greenhouses
- F. Measures of the composite effect of meteorological elements on life
- G. Weather and disease.

Section A provides an admirable description of radiation as affecting life with special attention to ultra-violet radiation. The outgoing radiation from plants and animals is not, however, neglected.

Section B distinguishes between the " large climate " of the well exposed stations of the synoptic reporting network, the " small climate " of a particular part of the landscape such as a valley or the different slopes of a hill, and, finally, the " microclimate " of the air layer next to the ground or within the plants or forest. " Small " and " micro " climates are very thoroughly treated from frost hollows to the air currents set up by the difference of temperature between a wood and surrounding open country. Three pages are devoted in this section to the effect of forests on rainfall in which, on the basis of a comparison of 8 years' readings in a growing forest in Germany with surrounding open country readings, he concludes that a forested area has up to 20 per cent. more rainfall than surrounding open country.

Only a relatively small section is devoted to agricultural meteorology and phenology. It is mainly concerned with the correlation between temperature and rainfall in spring with the subsequent harvest and the variation of this correlation with place. Protection of plants from frost is dealt with in detail. Of course much that is sometimes classed as agricultural meteorology has found a place in the previous section of the book.

Most aspects of the climate of cities are described in the next sections, special attention being given to temperature, visibility and rainfall. Examples are drawn mainly from Cologne but also from New York, London, Munich and Bremen.

The short section on the climate of rooms, factories, and greenhouses brings together much useful information including details of methods of air conditioning not readily available elsewhere.

With the section on measures of the composite effect of meteorological conditions we come to the effects of weather on man. The " measures " are Linke's Luftkorper, which are not quite the same as the air masses of synoptic meteorology, and the " rate of cooling " of a body at the temperature of the human skin determined by Hill's katothermometer and Dorno's frigorimeter. Tables of the rate of cooling are given for the main climatic regions and for the various types of air mass affecting central Europe.

The last section gives a very careful study of the elusive subject of the effects of weather on disease. In Germany and Austria much effort has been spent in attempts to ascertain pathological effects of the passage of fronts, the föhn, etc., by analysing statistics of the onset of certain illness on the days before, on, and after the occurrence of the particular meteorological phenomenon. There seems to be some evidence for real effects in the case of some diseases, notably apoplexy. Distinction is drawn between " meteorotropic " diseases for which meteorological events seem to provide a trigger action and seasonal illnesses whose incidence is not directly related to weather but more to seasonal changes in living conditions. The pitfalls which await the unwary in this subject on both the meteorological and medical sides are carefully noted.

The book concludes with a short bibliography in which only German books are given. Dr. Berg has given a great deal in the space at his disposal. Nevertheless, there are some items the reviewer considers might have found a place, if necessary at the expense of some relatively minor matters such as the " country breeze " between open country and a city which is described at length. Outstanding among the items referred to are :—

(*a*) shelterbelts in agricultural meteorology,

(*b*) transpiration of water vapour by trees and its effect on forest climate and the state of the soil,

(*c*) the subject best described by the title of Markham's book " Climate and the energy of nations ".

The author has no doubt suffered from lack of information from outside Germany during and since the war. Thus, his account of atmospheric pollution would have gained from a study of the Leicester pollution report.*

*London, Department of Industrial and Scientific Research, Atmospheric Pollution Research Committee. Atmospheric pollution in Leicester—A scientific survey. *Tech. Pap. D.S.I.R., London*, No. 1, 1945.

As it is he does not refer to the importance of the lapse-rate of temperature in the dispersal of industrial smoke. Similar comment applies to the recent work of Brunt on the human heat balance and tolerable climatic conditions.

The price of 7.50 *DM* is, at the rate of exchange of *1s.* 6*d.* to the mark, somewhat expensive for a paper-covered book of this size.

In spite of these criticisms there is no other book quite like this one which is strongly to be recommended.

G. A. BULL

On radiational cooling of the earth's surface during the night, especially with regard to the prediction of ground frosts, by P. Groen. *Meded. ned. met. Inst., de Bilt*, Serie B, 1, Nr. 9. Size : 12¼ in. × 8⅞ in., pp. 35. Rijksuitgeverij, The Hague, 1947, Price : *Fl.* 2,50.

In the present paper Dr. Groen first discusses the theoretical formulæ derived by Brunt* and Phillipps† for predicting the nocturnal radiational cooling of the ground, and then endeavours to eliminate certain of their simplifying assumptions which are at variance with observations. His assumption of a linear variation of effective radiation with decrease of temperature appears to be an improvement on the earlier assumptions of a constant effective radiation but his assumption of an initial linear distribution of temperature with depth in the ground is more debatable.

In Brunt's discussion of the problem the flow of heat from the air to the ground and the heat released by the deposition of dew are ignored, which leads to an overestimate of the degree of cooling. Phillipps took into account the first of these by assuming that the air had a constant coefficient of eddy conductivity, but Dr. Groen objects to this on the grounds that it is unlikely that the coefficient of eddy conductivity is a constant and that the role of radiation in the heat exchange of the air has been neglected. In view of the difficulties in dealing with these aspects of the problem, Dr. Groen abandons theory in favour of empiricism. It is difficult to see the value of the present approach and the theoretical approach of J. C. Jaeger‡ would appear to be not only simpler but far superior.

R. FROST

Interdiurnal variations of pressure and temperature in the upper atmosphere over North India, by M. W. Chiplonkar. Scientific Notes of the India Meteorological Department. Vol. IX, No. 109. 8vo. pp. 81–92. Delhi, Manager of Publications, 1947. Price : *Annas* 14 or *1s.* 3*d.*

M. W. Chiplonkar has analysed the changes of pressure and temperature at various levels over Agra on 114 pairs of days in winter. The data were taken from published results of sounding-balloon ascents, and the time interval between the ascents was usually 24 hours. The analysis follows the lines adopted by Haurwitz and other American authors in treating European and North American data.

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*BRUNT, D.; Notes on radiation in the atmosphere. *Quart. J. R. met. Soc., London*, **58**, 1932 p. 389.

†PHILLIPPS, H.; Zur Theorie der Wärmestrahlung in Bodennähe. *Beitr. Geophys., Stuttgart*, **56**, 1940, p. 229.

‡JAEGER, J. C.; Note on the effect of wind on nocturnal cooling. *Quart. J. R. met. Soc., London*, **71**, 1945, p. 388.

The pairs of observations are classified according to the sign of the pressure change at the ground, and the corresponding mean pressure and temperature changes at upper levels are tabulated and graphed. The results obtained in this way are not always easy to interpret, but Chiplonkar finds that the pressure and temperature variations over North India, although smaller than those over Europe and North America, have a broadly similar distribution with height.

It is unfortunate that no indication is given of instrumental accuracy, since errors so introduced would increase upward and if large enough would distort the apparent height variation of the interdiurnal changes. However, Chiplonkar finds that pressure changes at 6–11 Km. are as great or greater than those at the surface, and that pressure changes at 4 Km. are more definitely associated with tropospheric temperature changes. Perhaps we may conclude that upper air isobaric charts might provide a useful tool in north India where surface isobars are very difficult to interpret.

J. S. SAWYER

NEWS IN BRIEF

Mr. R. H. Mathews, B.A., has been appointed Assistant Director (Climatology) of the Meteorological Office.

OBITUARY

Father F. J. Rowland, S.J.—The news of the death of Father F. J. Rowland, S.J., Director of the Stonyhurst College Observatory from 1932 to 1947 has been received. Before becoming Director Father Rowland worked in the Observatory for many years under Father O'Connor his predecessor.

A note on the meteorological work of the Stonyhurst Observatory was published in the August 1948 number of this magazine.

The Observatory, under Father Rowland's control, was very actively engaged in terrestrial magnetism, solar physics, and in seismology as well as in meteorology.

WEATHER OF JANUARY 1949

On the first day of the month a very deep depression moved north-north-east across Ireland and Scotland, and other depressions moved eastwards across the British Isles on the 4th, and across northern Scotland during the night of the 7th. Subsequently the tracks of depressions were mostly far to the north and north-west of Scotland, and anticyclones lay near to or over the British Isles, mostly to southward and south-westward of these islands up to the 22nd, and then over the continent. An anticyclone, centred directly over the British Isles on the 30th and 31st, gave readings above 1044 mb. over Ireland and most of England during the morning of the 30th.

Mean pressure for the month was above 1025 mb. between the Azores and southern Germany. It was above 1020 mb. over most of North America, and above 1025 mb. over an area including the most westerly States of the U.S.A. and the south-west of Canada, but was below 990 mb. between Jan Mayen and the north of Norway. Mean pressure was above normal by more than 10 mb. around British Columbia and by more than 5 mb. in an area between Nova Scotia and Hungary bounded roughly by latitudes 45° and 55°N. The only region with pressure much below the normal included Finland, Scandinavia and the Arctic Ocean, the deficit exceeding 10 mb. in northern Scandinavia.

In the British Isles the weather was unsettled and wet in the north-west and extreme north and dry and sunny on the whole in the south and east. Westerly winds and mild conditions predominated. Pressure fell to the

exceedingly low level of 950 mb. at Holyhead on the 1st and the monthly range of pressure at Kew Observatory, namely 82 mb., was the greatest in any one month since observations began there in 1869.

On the 1st an intense depression centred over Ireland moved north-east and then turned north to a position off west Norway by the morning of the 3rd. South-westerly gales occurred in south England, and north-easterly gales in north Scotland on the 1st, while gusts of 78 kt. and 71 kt. were registered respectively at Tangmere, Sussex, and Manston, Kent. Heavy rain fell locally in Scotland; for example 2·33 in. at Achfary, Sutherland. In the rear of this disturbance cold winds of polar origin prevailed in the British Isles. On the 4th a depression moved from north-west Ireland to East Anglia and snow fell in Northern Ireland, north England and extreme south-west Scotland, while over parts of Scotland frost continued throughout the day. By the 6th pressure was high from the Bay of Biscay across France to the Caspian Sea; meanwhile a weak trough of low pressure moved across north Ireland and south Scotland giving considerable rain locally in Scotland and the Lake District with 2·00 in. at Borrowdale, Cumberland. On the 7th a depression moved east over Scotland and caused widespread gales on the 7th and 8th and further rain, particularly in the west and north. Meanwhile an intense anticyclone developed on the Atlantic and subsequently drifted south where it remained off our south-west coasts until the 21st. During this period deep depressions to the north of Scotland moved east giving gales locally, chiefly in the northern half of the country, on the 11th, 16th, 17th, 19th and 20th and mainly mild weather, dry on the whole over most of England but wet in the north and west of Scotland. On the 18th, 2·18 in. of rain was measured at Inveraray Castle Gardens, Argyll, and 2·03 in. at Fort William. Subsequently the anticyclone moved slowly east and on the 24th and 25th a new high moved east across England to central Europe; mainly dry conditions became established over most of the British Isles, apart from rain at some places in the west and north. There was a good deal of fog at some inland stations in England from the 26th to 29th; it was particularly thick in parts of London on the 29th. The week ending the 29th was, however, very sunny at those places which escaped most of the fog. On the 29th yet another anticyclone developed off the west of Ireland and moved east. On the 31st a small disturbance off the north of Scotland moved south-east over the North Sea and was associated with slight rain over much of the country.

The month was wet in the west and north of Scotland, more than twice the average rainfall occurring over much of Sutherland, but less than the average in the east and extreme south-west of Scotland. In England and Wales it was the driest January over the country since 1911.

The general character of the weather is shown by the following provisional figures:—

	Air Temperature			Rainfall		Sunshine	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average	Percentage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales	57	17	+2·1	58	−4	114	22
Scotland	57	0	+1·4	127	+1	87	16
Northern Ireland ..	54	15	+2·6	104	0	86	16

RAINFALL OF JANUARY 1949

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
London	Camden Square	·75	40	*Glam.*	Cardiff, Penylan	1·24	34
Kent	Folkestone, Cherry Gdns.	1·69	75	*Pemb.*	St. Ann's Head	·96	28
,,	Edenbridge, Falconhurst	1·37	56	*Card.*	Aberystwyth	2·23	69
Sussex	Compton, Compton Ho.	1·44	45	*Radnor*	Bir. W. W., Tyrmynydd	3·37	53
,,	Worthing, Beach Ho. Pk.	1·25	54	*Mont.*	Lake Vyrnwy	4·71	85
Hants	Ventnor, Roy. Nat. Hos.	1·08	42	*Mer.*	Blaenau Festiniog	11·20	110
,,	Bournemouth	·76	28	*Carn.*	Llandudno	2·36	98
,,	Sherborne St. John	1·11	48	*Angl.*	Llanerchymedd	3·10	98
Herts.	Royston, Therfield Rec.	1·21	70	*I. Man.*	Douglas, Boro' Cem.	2·91	87
Bucks.	Slough, Upton	1·09	59	*Wigtown*	Port William, Monreith	2·25	69
Oxford	Oxford, Radcliffe	·91	50	*Dumf.*	Dumfries, Crichton R.I.	2·43	76
N'hant.	Wellingboro', Swanspool	·73	39	,,	Eskdalemuir Obsy.	6·81	126
Essex	Shoeburyness	·86	64	*Roxb.*	Kelso, Floors	2·21	126
Suffolk	Campsea Ashe, High Ho.	·95	52	*Peebles*	Stobo Castle	4·18	139
,,	Lowestoft Sec. School	1·12	67	*Berwick*	Marchmont House	1·83	81
,,	Bury St. Ed., Westley H.	1·09	61	*E. Loth.*	North Berwick Res.	1·54	90
Norfolk	Sandringham Ho. Gdns.	1·20	62	*Midl'n.*	Edinburgh, Blackf'd. H.	2·16	123
Wilts.	Bishops Cannings	1·10	47	*Lanark*	Hamilton W. W., T'nhill	4·37	133
Dorset	Creech Grange	1·15	35	*Ayr*	Colmonell, Knockdolian	3·94	91
,,	Beaminster, East St.	1·06	30	,,	Glen Afton, Ayr San	..	..
Devon	Teignmouth, Den Gdns.	·45	15	*Bute*	Rothesay, Ardencraig	5·99	133
,,	Cullompton	·97	30	*Argyll*	L. Sunart, Glenborrodale	9·15	129
,,	Barnstaple, N. Dev. Ath.	1·18	36	,,	Poltalloch	7·21	142
,,	Okehampton, Uplands	2·40	47	,,	Inveraray Castle	13·92	169
Cornwall	Bude School House	1·27	42	,,	Islay, Eallabus	5·46	117
,,	Penzance, Morrab Gdns.	1·97	52	,,	Tiree	4·99	117
,,	St. Austell, Trevarna	2·14	50	*Kinross*	Loch Leven Sluice	3·61	115
,,	Scilly, Tresco Abbey	1·46	46	*Fife*	Leuchars Airfield	1·04	57
Glos.	Cirencester	1·19	47	*Perth*	Loch Dhu	10 39	114
Salop.	Church Stretton	1·72	66	,,	Crieff, Strathearn Hyd.	..	..
,,	Cheswardine Hall	2·10	95	,,	Pitlochry, Fincastle	2·75	79
Staffs.	Leek, Wall Grange P.S.	1·69	58	*Angus*	Montrose, Sunnyside	1·28	64
Worcs.	Malvern, Free Library	1·20	54	*Aberd.*	Balmoral Castle Gdns.	2·07	75
Warwick	Birmingham, Edgbaston	1·38	68	,,	Dyce, Craibstone	1·85	78
Leics.	Thornton Reservoir	1·18	60	,,	Fyvie Castle	2·44	103
Lincs.	Boston, Skirbeck	1·06	65	*Moray*	Gordon Castle	2·61	129
,,	Skegness, Marine Gdns.	1·15	66	*Nairn*	Nairn, Achareidh	2·87	159
Notts.	Mansfield, Carr Bank	1·01	47	*Inv's*	Loch Ness, Foyers	7·66	182
Ches.	Bidston Observatory	2·14	101	,,	Glenquoich	22·29	162
Lancs.	Manchester, Whit. Park	2·07	82	,,	Fort William, Teviot	14·22	147
,,	Stonyhurst College	3·19	75	,,	Skye, Duntuilm	6·66	126
,,	Blackpool	2·12	78	*R. & C.*	Ullapool	5·65	127
Yorks.	Wakefield, Clarence Pk.	·82	43	,,	Applecross Gardens	8·89	163
,,	Hull, Pearson Park	·89	49	,,	Achnashellach	16·47	181
,,	Felixkirk, Mt. St. John	·82	41	,,	Stornoway Airfield	6·05	123
,,	York Museum	·68	38	*Suth.*	Lairg	7·84	239
,,	Scarborough	·87	43	,,	Loch More, Achfary	15·92	219
,,	Middlesbrough	·60	37	*Caith.*	Wick Airfield	3·99	162
,,	Baldersdale, Hury Res.	2·11	65	*Shet.*	Lerwick Observatory	5·68	133
Norl'd.	Newcastle, Leazes Pk.	·58	29	*Ferm.*	Crom Castle	3·41	102
,,	Bellingham, High Green	2·31	81	*Armagh*	Armagh Observatory	2·41	96
,,	Lilburn Tower Gdns.	1·05	51	*Down*	Seaforde	2·18	69
Cumb.	Geltsdale	2·80	100	*Antrim*	Aldergrove Airfield	2·48	91
,,	Keswick, High Hill	4·42	88	,,	Ballymena, Harryville	3·53	95
,,	Ravenglass, The Grove	3·06	91	*Lon.*	Garvagh, Moneydig	3·59	104
Mon.	Abergavenny Larchfield	1·33	39	,,	Londonderry, Creggan	5·74	159
Glam.	Ystalyfera, Wern House	3·54	56	*Tyrone*	Omagh, Edenfel	4·16	118

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, SEPTEMBER 1948

Stations	Pressure: Mean of day M.S.L.	Pressure: Diff. from normal	Temperatures: Absolute Max.	Temperatures: Absolute Min.	Temperatures: Mean values Max.	Temperatures: Mean values Min.	Temperatures: Mean values ½ Max. and Min.	Temperatures: Mean values Diff. from normal	Temperatures: Mean values Wet bulb	Relative humidity	Mean cloud amount	Precipitation: Total	Precipitation: Diff. from normal	Precipitation: Days	Bright Sunshine: Daily mean	Bright Sunshine: Percentage of possible
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	tenths	in.	in.		hr.	%
London, Kew Observatory	1017·2	0·0	74	39	65·1	51·6	58·3	+0·8	55·0	81	7·2	1·24	−0·63	9	5·1	41
Gibraltar	1017·8	+0·6	84	61	79·0	66·3	72·7	+0·3	68·1	80	3·1	0·00	—	0	10·4	84
Malta	1016·4	+0·1	84	63	80·0	67·4	73·7	−2·3	70·2	70	5·1	0·05	—	3	9·6	77
St. Helena	1018·2	−0·5	67	52	62·5	54·5	58·5	+1·6	54·5	94	9·9	1·03	−1·22	8	—	—
Lungi, Sierra Leone ..	1012·9	—	86	69	82·9	72·9	77·9	—	74·3	90	8·8	22·59	—	27	—	—
Lagos, Nigeria ..	1013·5	+1·3	87	68	83·7	69·8	76·7	−2·0	74·1	82	9·3	2·62	—	14	3·1	26
Kaduna, Nigeria ..	1011·6	—	89	62	84·5	66·5	75·5	−0·4				10·22	−1·28	23	5·6	46
Chileka, Nyasaland ..	1018·4	−0·2	93	51	82·7	60·5	71·6	−0·9	60·5	51	2·0	0·04	−0·14	1	8·3	69
Lusaka, Rhodesia ..	1014·5	0·0	94	44	85·7	56·8	71·3	−0·2	54·8	37	1·6	0·00	−0·04	0	9·8	82
Salisbury, Rhodesia ..	1016·3	−1·4	88	38	78·8	52·1	65·5	−0·3	52·3	44	1·4	0·00	−0·20	0	9·5	79
Cape Town ..	1019·0	−0·1	87	40	64·8	48·5	56·7	−1·2	48·3	71	6·6	2·68	+0·44	15	—	—
Germiston, South Africa	1019·0	+0·6	80	33	74·8	46·7	60·7	+1·0	45·0	36	1·0	0·04	−0·77	2	10·6	89
Mauritius																
Calcutta, Alipore Obsy.	1000·2	−4·3	94	77	89·5	79·1	84·3	+1·1	79·8	91	7·7	6·50	−3·51	19	4·6	37
Bombay	1006·8	−1·2	89	73	85·4	75·9	80·7	−0·2	75·9	89	7·5	11·78	+1·10	23	4·6	37
Madras	1005·8	−0·7	101	73	94·1	77·6	85·9	+0·7	75·2	74	8·2	4·14	−0·71	14	5·5	45
Colombo, Ceylon ..	1010·1	+0·2	88	72	86·3	76·5	81·4	+0·2	76·1	82	6·9	2·18	−2·58	14	8·2	67
Singapore	1009·9	+0·1	91	73	87·6	75·7	81·7	+0·6	76·7	79	7·8	5·62	−1·17	13	—	—
Hong Kong	1008·1	−0·2	92	71	86·6	76·3	81·5	+0·5	76·9	83	—	22·85	+13·16	16	6·4	52
Sydney, N.S.W. ..	1016·1	0·0	84	44	68·0	51·2	59·6	+0·4	53·3	65	6·3	2·83	−0·03	12	6·5	55
Melbourne	1014·9	−0·9	79	37	65·8	45·5	55·7	+1·6	50·0	62	5·5	1·96	−0·48	15	5·7	48
Adelaide	1017·6	+0·1	88	43	67·9	48·7	58·3	+1·1	51·2	56	6·9	0·69	−1·39	10	6·2	53
Perth, W. Australia ..	1017·3	−0·2	77	43	66·6	49·5	58·1	−0·1	54·5	70	5·2	5·07	+1·65	13	6·2	52
Coolgardie	1017·5	+0·3	89	38	74·5	47·3	60·9	+2·2	50·3	44	2·8	0·48	−0·19	3	—	—
Brisbane	1015·9	−1·7	90	47	74·6	54·8	64·7	−0·5	57·1	60	3·7	2·98	+0·98	7	8·2	69
Hobart, Tasmania ..																
Wellington, N.Z. ..	1013·4	−1·2	64	40	57·8	46·0	51·9	+1·8	49·3	80	7·8	1·37	−2·60	14	5·3	45
Suva, Fiji	1013·0	−1·3	88	64	81·2	69·8	75·5	+1·0	71·2	80	6·6	1·72	−5·97	12	6·5	54
Apia, Samoa ..	1011·8	0·0	87	68	85·5	71·9	78·7	−0·2	75·8	74	3·2	2·34	−3·20	10	9·3	78
Kingston, Jamaica ..	1011·5	−0·7	95	72	90·5	74·9	82·7	+1·2	76·7	76	4·8	5·34	+1·31	10	7·5	61
Grenada, W. Indies ..	—	—	90	72	87·0	75·4	81·2	+0·9	77·8	80	7·7	4·51	−3·48	19	—	—
Toronto	1018·0	+0·2	90	44	75·5	56·1	65·8	+5·5	55·4	77	5·7	2·22	−0·45	7	7·5	60
Winnipeg	1015·4	+1·6	93	37	75·2	49·1	62·1	+8·4	46·2	66	5·0	0·05	−2·71	3	8·3	66
St. John, N.B. ..	1015·7	−1·7	76	40	64·7	48·9	56·8	+0·9	51·3	89	6·4	1·75	−1·99	11	5·9	47
Victoria, B.C. ..	1016·2	−0·2	77	38	63·8	47·5	55·7	−0·4	48·8	94	5·2	1·81	0·00	9	7·1	56